Development of a Measurement Operator for Cosmic Ray Soil Moisture Observations

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Introduction

Soil moisture estimations at intermediate scale are key input variables for hydrological, land surface and climate models. Recently cosmic ray probes were proposed for collecting soil moisture information at intermediate scale (Zreda et al., 2008). Cosmic ray probes measure neutron fluxes close to the earth surface. Effective absorption of neutrons by hydrogen nuclei in the soils yields a high inverse correlation between neutron flux and soil moisture. However, the relation between horizontal and vertical distribution of soil moisture content in the footprint of a cosmic ray probe and neutron counts is non-linear and the exact relationship is still subject to research and uncertainty.

The motivation of this study is the development of a data assimilation measurement operator. With the measurement operator we aim to update simulation results of a land surface model. In this context there are nine cosmic ray sensors deployed in the Rur catchment, Germany.

The objective of this study is to evaluate and improve the understanding of cosmic ray soil moisture measurements on footprint scale. We relate continuous multi-seasonal in situ soil moisture measurements across the horizontal and vertical footprint scale to cosmic ray soil moisture estimations.

Methods

Test site: Managed grass land, pre-dominant soil type: Loam

- Over 504 time domain transmissivity (TDT) sensors installed in 5, 20 and 50 cm depth
- One cosmic ray probe measuring from May 20th, 2011
- Additional measurements: Temperature, air humidity, air pressure, precipitation, eddy co-variance station

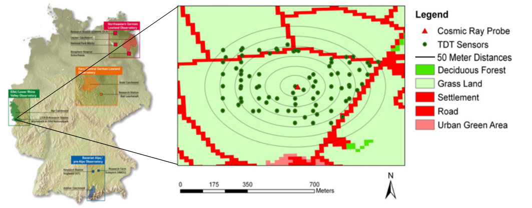

Fig. 1: Locations of the TERENO Observatories in Germany; location of the field site Rollesbroich used for validation, land use, positions of cosmic ray probe and TDT sensors in the vicinity.

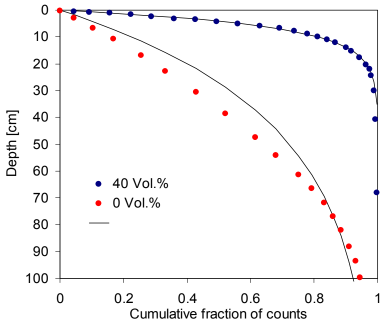

Fig. 2: Performance of the weighting function for 0% soil water content and 40% soil water content in various depths compared to monte carlo neutron particle modeling results (Zreda et al., 2008).

- Pressure correction and correction for incoming neutrons were applied on raw neutron counts per hour
- Use of parameters and calibration function for cosmic ray method (eq. 1) from Desilets et al. (2010)
- Derivation of vertical weighting function through best-fit of eq. 2 to the depth z_i at 86% cumulative fraction of counts (Fig. 2)
- The derived vertical weighting function eq. 4 is applied on the horizontally weighted soil water content measurements in three depths of the soil moisture sensor network

$$\theta_{vol} = \frac{a_0}{(N_{corr}/N_0) - a_1} - a_2 \qquad \text{Equation 1}$$

$$z_i = \alpha \cdot \ln(1 - CFoC) \qquad \text{Equation 2}$$

$$\alpha = \frac{-5.8}{\ln(0.14) \cdot (\theta + 0.0829)} \qquad \text{Equation 3}$$

$$w_z = 1 - e^{\left(-\frac{z}{\alpha}\right)} \qquad \text{Equation 4}$$

Θ_{vol} – volumetric soil water content
a_0 - a_2 – fitting parameters
N_{corr} – corrected neutrons / hour
N_0 – Neutron source calibration parameter
z_i – depth i [cm]
CFoC – Cumulative fraction of counts
α – fitting parameter for vert. weighting
w_z – weight of soil water content in depth z

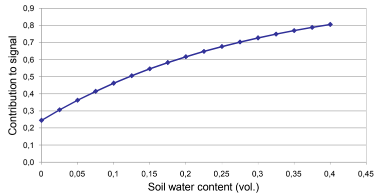

Fig. 3: Weight (w_z) of TDT soil water content measurement in 5cm depth on the cosmic ray signal. Calculation used equation 4 assuming a measurement validity for 0 to 10 cm depth.

Results

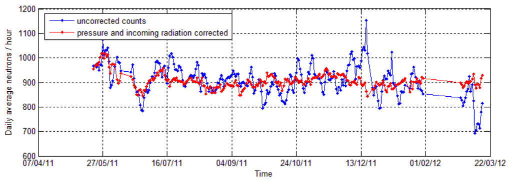

Fig. 4: Uncorrected daily averaged neutron counts per hour monitored by the cosmic ray probe in Rollesbroich and daily average counts corrected for pressure and incoming radiation.

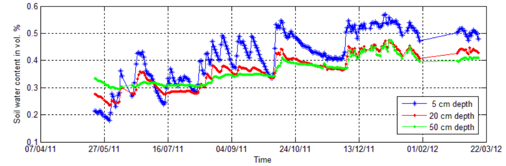

Fig. 5: Daily averaged horizontal weighted soil water content in three depths at the field site Rollesbroich.

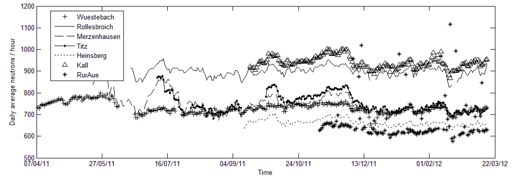

Fig. 6: Daily averaged neutron counts per hour at eight locations in the Rur catchment.

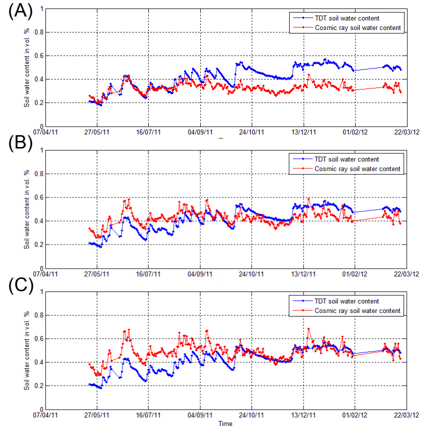

Fig. 7: Estimated soil water content and vertical weighted soil water content (TDT soil water content) at the field site Rollesbroich for 3 calibration periods: (A) first three months 20th May – 20th Aug. 2011; (B) 20th May 2011 – 17th Mar. 2012; (C) 17th Dec. 2011 – 17th Mar. 2012. Equation (1) was optimised for parameter N0 only on a least minimum sum of squared error. R² and RMSE are for the calibration period respectively.

Tab. 1: N0 calibration results, R² and RMSE for the respective calibration periods of Fig. 7.

	N0	R^2	RMSE
A	1627	0.85	0.028
B	1747	0.34	0.078
C	1780	0.26	0.043

Conclusion

- For the calibration period of the first three months the weighting function was able to weight soil water content well; the strong changing gradient could be well represented in the comparison of cosmic ray soil water content estimation
- Calibration for the first 3 months and the last 3 months gave reasonable soil moisture evaluations for the respective periods
- However, for all three calibration periods soil water content is partially systematically over- or under-estimated by ε > 0.1 vol.%
- Periods of over- or under-estimation seem to be influenced by long term effects not taken into account yet

Outlook

- Quantify performance of correction methods and sources for offsets in soil water content estimation
- Evaluate linear and non-linear weighting of vertical soil moisture content distribution

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References

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